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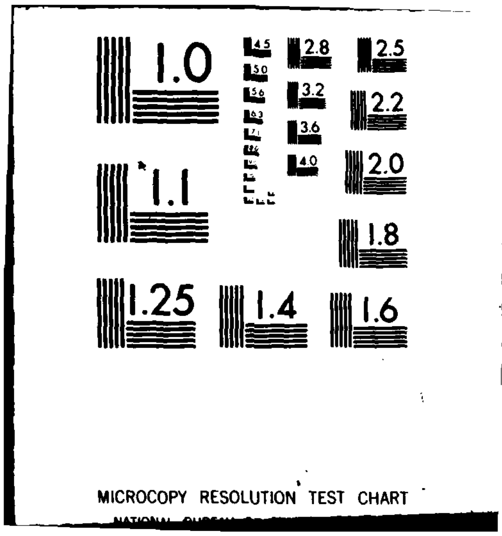
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INSTRUCTION REPORT K-80-4

A THREE-DIMENSIONAL STABILITY ANALYSIS/DESIGN PROGRAM (3DSAD)

Report 3

GENERAL ANALYSIS MODULE (CGAM)

by

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June 1982
Report 3 of a Series

A report under the Computer-Aided Structural Engineering (CASE) Project

Prepared for Office, Chief of Engineers, U. S. Army
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Stability
Structural stability
3DSAD (Computer program)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the General Analysis Module of the three-dimensional stability analysis/design (3DSAD) program. The module performs overturning, bearing (base pressure), and sliding computations for a structure. The report presents both a user's guide and a theoretical discussion for the module.

Input to the module consists of:

a. The definition of the area or surface of investigation

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20. ABSTRACT (Continued)

(generally the base of the structure) by points, line segments, and their connectivity.

b. The sum total of the forces (F_x, F_y, and F_z) and moments (M_x, M_y, and M_z), excluding uplift, considered to compose the load case. The forces and moments are given in consistent units.

c. Uplift data consisting of uplift pressure in consistent units at each point on the base.

d. Foundation data used for computing the structure's resistance to sliding consisting of the shear strength in consistent units and the phi angle in degrees.

To do an analysis, the module:

a. Defines a plane of analysis. A modified base can be used which is a planar approximation (least squares fit) of an irregular surface of investigation (original base).

b. Using the general flexure equation, computes the base pressures for each point on the base.

c. If any of the pressures are negative, computes the new effective base, modifies the uplift for category 1 and 2 load cases, and repeats the base pressure computation. This process continues until all the computed pressures are positive (compression) or zero.

d. Computes a shear friction factor of safety in the specified direction.

Output consists of:

a. A printout of:

(1) Input data.

(2) Area properties.

(3) Summary of forces and moments.

(4) (X,Y,Z) coordinates and base pressures for points defining the modified base.

(5' Percent effective base and shear friction factor of safety.

b. Plot of outline, kern, and centroid of the base and position of the load resultant.

PREFACE

This report documents the General Analysis Module of the three-dimensional stability analysis/design (3DSAD) program. The module was developed at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., in the Automatic Data Processing (ADP) Center by Mr. Fred T. Tracy. The work was sponsored through funds provided WES by the Civil Works Directorate, Office, Chief of Engineers, U. S. Army (OCE), under the Computer-Aided Structural Engineering (CASE) Project.

Specifications for the program were provided by the members of the CASE Task Group on 3D Stability. The members of the task group during the period of development were as follows:

Mr. Charles W. Kling, Mobile District (Chairman)
Mr. Robert Haavisto, Sacramento District
Mr. John Hoffmeister, Nashville District
Mr. Gerrett L. Johnson, Seattle District
Mr. Thomas J. Mudd, St. Louis District
Mr. William Holtham, New England Division

This report was written by Mr. Tracy and Mr. Charles W. Kling, Mobile District. Mr. Kling also contributed significantly as an experienced practicing engineer. Mr. Donald R. Dressler, Structures Division, Civil Works Directorate, OCE, and Dr. Howard B. Wilson, Jr., University of Alabama, are acknowledged for their contributions to the kern plot. Ms. Debra G. Biedenharn and Mr. Kenneth W. Trahan, ADP Center, are acknowledged for programming support.

Mr. Donald R. Dressler, was also the OCE point of contact. The work was done under the direction of Dr. N. Radhakrishnan, Special Technical Assistant, ADP Center. Mr. Dressler and Dr. Radhakrishnan also contributed in the definition of general concepts for the development of 3DSAD. Mr. Donald L. Neumann was Chief, ADP Center.

Directors of WES during the preparation and publication of this report were COL N. P. Conover, CE, and COL T. C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

A THREE-DIMENSIONAL STABILITY ANALYSIS/DESIGN PROGRAM (3DSAD)

GENERAL ANALYSIS MODULE (CGAM)

PART I: INTRODUCTION

Overview of the 3D Stability Program

1. The objective of the Computer-Aided Structural Engineering (CASE) Task Group on Three-Dimensional (3D) Stability Analysis is to develop computer programs that will help design engineers perform stability computations for general 3D structures. To enable this, a computer program called 3DSAD (three-dimensional stability analysis/design) is being developed in a modular fashion. Initially, 3DSAD will have three general modules:

a. General Geometry Module. This will:

(1) Define geometry based on two-dimensional (2D) cross sections extended in the third dimension, eight-node brick elements, or clusters of planar polygonal patches.

(2) Perform centroid, volume, and weight computations on described geometry.

(3) Employ interactive graphics extensively.

b. General Loads Module. This will compute loads on general 3D structures based on input of geometry, water levels, soil strata descriptions, etc.

c. General Analysis Module. This will perform overturning, bearing, and sliding computations.

The engineer performing an analysis of any 3D structure will be able to interact directly with the above modules.

2. Besides the general capabilities that are useful for any 3D structure, 3DSAD will also provide for simplified geometry and load input along with criteria check modules for some specific structures. This latter capability will permit interactive design of these structures. Examples of

some specific structures for which modules will be developed are dams, locks, walls, powerhouses, and pumping stations.

3. A specific structure input module requires less data than that for a general structure. Modules of this type will interact with the General Geometry Module and the General Loads Module to define the geometry and loads internally in the program. After analysis, a specific structure criteria check module will check pertinent values, change dimensions (if necessary), and cycle through the computation. A general schematic of the 3DSAD program is shown in Figure 1.

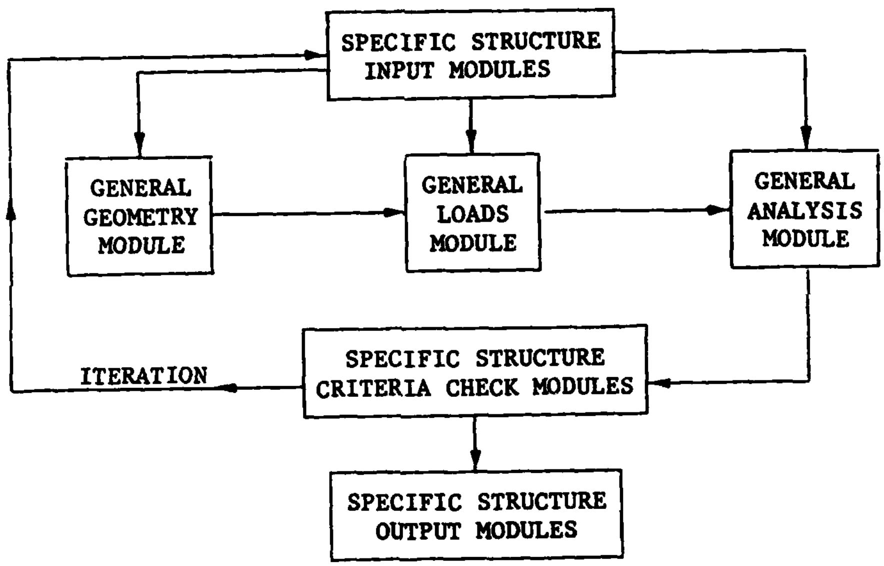

Figure 1. General schematic of 3DSAD

4. The 3DSAD program will be developed in phases. During the first phase, the three general modules are being developed. This approach will enable the stability analysis of any 3D structure although the input may be more complicated than need be for some specific structures. In the subsequent phases, the special input and criteria check modules will be developed for several specific structures.

The General Analysis Module

5. This report contains both a user's guide and a theoretical discussion for the General Analysis Module. As stated above, this module performs overturning, bearing (base pressures), and sliding computations for a structure.

Input

6. Input to the module consists of:

   a. The definition of the area or surface of investigation (generally the base of the structure) by points, line segments, and their connectivity.

   b. The sum total of the forces (F_x, F_y, and F_z) and moments (M_x, M_y, and M_z), excluding uplift, considered to compose the load case. The forces and moments are given in consistent units.

   c. Uplift data consisting of uplift pressure in consistent units at each point on the base.

   d. Foundation data used for computing the structure's resistance to sliding consisting of the shear strength in consistent units and the phi angle in degrees.

Analysis

7. To do an analysis, the module:

   a. Defines a plane of analysis. A modified base can be used which is a planar approximation (least squares fit) of an irregular surface of investigation (original base).

   b. Using the general flexure equation, computes the base pressures for each point on the base.

   c. If any of the pressures are negative, computes the new effective base, modifies the uplift for category 1 and 2 load cases, and repeats the base pressure computation. This process continues until all the computed pressures are positive (compression) or zero.

   d. Computes a shear friction factor of safety in the specified direction.

Output

8. Output consists of:

<u>a</u>. A printout of:

(1) Input data.

(2) Area properties.

(3) Summary of forces and moments.

(4) (X,Y,Z) coordinates and base pressures for points defining the modified base.

(5) Percent effective base and shear friction factor of safety.

<u>b</u>. Plot of outline, kern, and centroid of the base and position of the load resultant.

Coordinate System

9. The coordinate system is shown in Figure 2. Note that

Figure 2. Coordinate system

X is to the right, Z is up, and Y is "into" the page. This is a right-handed system. Most bases considered in the analysis will be in the X-Y plane (horizontal) or nearly so. Note also that moments are considered counterclockwise positive (right-hand screw rule).

PART II: USER'S GUIDE

Introduction

10. Although the General Analysis Module can be used in conjunction with specific structures such as dams, this input guide describes how it can be used as a separate module. Data are in the form of commands that the user either interactively inputs or saves in a data file to be read and executed by the module at one time. (See Appendix A for details on creating and modifying data files.)

Running the Program

11. 3DSAD is designated X8100 in the Conversationally Oriented Real-Time Program-Generating System (CORPS) library. Thus, to initiate the program, the user types the command on his respective system that executes program X8100 from the CORPS library. The computer first responds with

3DSAD - CASE

STRUCTURE TYPE OR GENERAL MODULE?

A ? response produces

A THREE-DIMENSIONAL STABILITY ANALYSIS/DESIGN PROGRAM

(3DSAD)

A PRODUCT OF

Computer Aided Structural Engineering

(CASE)

◇ ◇ ◇ ◇ ◇ ◇

ER ?, HELP, OR WHAT TO GET VALID RESPONSES.

ER STOP, END, QUIT, OR DONE TO TERMINATE PROGRAM.

ID STRUCTURE TYPES ARE: LOCKS, DAMS, POWERHOUSES, WALLS, PUMP
TIONS, AND INTAKES.

ID GENERAL MODULE TYPES ARE: GEOMETRY, LOADS, AND ANALYSIS

UCTURE TYPE OR GENERAL MODULE ?

then gives

ANAL

eneral Analysis Module.

The next question the program asks is

RESTART FILE NAME OR CR?

t" stands for carriage return. The restart file saves all data that has thus far input either from another data file or by typing ively. (Note: utility commands such as INPUT, END, etc., are not The user gives a carriage return if he does not want a restart file.

The next question is

COMMAND?

ands will be discussed in detail in the next section.

Commands

14. The program uses commands (POINTS, BASE, CASE, etc.) to build the data. The commands are:

a. Data building:

POINT UPLIFT
CIRCLE ELLIPSE
QUADRATIC
PHI SHRSTR
SANGLE DENSITY
BASE CASE

b. Utility:

INPUT END
GO RETURN
CLEAR

This list is obtained by typing "?" at the command level. Only the minimum number of letters of a command need to be given. The user can, however, type the entire word if he prefers. Commands and their accompanying data can be put into a data file or typed interactively while the program is running. All lines in data files created for 3DSAD must be assigned line numbers. A file can be input at the command level by typing INPUT and then the file name. This procedure is described in detail in paragraph 31 below.

15. Each command will now be described in detail. In giving the format for the commands, actual letters to be typed will be enclosed in quotes to distinguish them from variable names. The quotes do not have to be typed when the user issues the command. The required letters are shown in capital letters; the optional letters are shown in lower letters.

POINTS

16. The user first defines a minimum of three points representing the vertices of the base using the POINTS command. Its format is

"POints" NPT

where NPT is the number of points. After this line, a one- to four-character identification label and the (X,Y,Z) coordinates for each point are given.

17. Interactive mode. Below is an example of the POINTS command done interactively on a CDC system (all data provided in the examples in this report have units of feet for distance and kips for force):

```
 COMMAND ?
I>POINTS 4
 LABEL, X, Y, Z
I>1 0 0 268
I>2 54 0 268
I>3 54 32 268
I>4 0 32 268
```

18. Data file mode. The same data are put in a file as shown below:

```
10 POINTS 4
20 1 0 0 268
30 2 54 0 268
40 3 54 32 268
50 4 0 32 268
```

Note that these four points could form a horizontal rectangular base at elevation 268.

CIRCLE

19. After the user has defined some points to work with, he must then define any curved line segments. That is, line segments between points are assumed straight unless otherwise specified. A circular arc may be defined by using the CIRCLE command as follows:

```
"Circle" N1 N2 R "Left"
"Circle" N1 N2 R "Right"
```

N1 and N2 are two point numbers between which a circular arc of radius R is being defined. "LEFT" and "RIGHT" designate, respectively, on which side of the line segment the center of the circle is when progressing from N1 to N2.

If not designated, "LEFT" is assumed. The following data file results in the base shown in Figure 3:

```
10 POINTS 4
20 1 0 -5
30 2 5 0
40 3 0 5
50 4 -5 0
60 CIRC 1 2 5
70 CIRC 2 3 5 LEFT
80 CIRC 4 3 5 RIGHT
90 CIRC 4 1 5
```

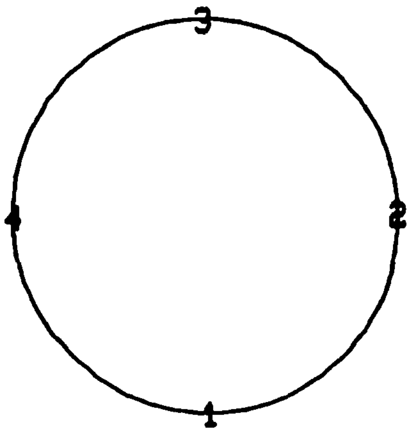

Figure 3. CIRCLE command

20. Circles can be defined only in the X-Y plane.

<u>ELLIPSE</u>

21. The user can define an elliptical line segment using the ELLIPSE command:

"ELlipse" N1 N2 A B "Left"
"ELlipse" N1 N2 A B "Right"

N1 and N2 are two point labels between which an elliptical arc having semimajor axis length A and semiminor axis length B is drawn. "LEFT" and

"RIGHT" have the same meaning as in the CIRCLE command. The following data file results in the base shown in Figure 4:

```
10 POINTS 4
20 1 0 -5
30 2 10 0
40 3 0 5
50 4 -10 0
60 ELLI 1 2 10 5
70 ELLI 2 3 10 5 LEFT
80 ELLI 4 3 10 5 RIGHT
90 ELLI 4 1 10 5
```

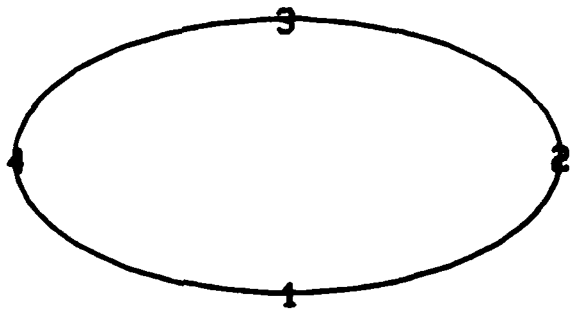

Figure 4. ELLIPSE command

Note that the semimajor and semiminor axes are always parallel to the coordinate axes.

22. As with the CIRCLE command, the ellipse can be defined only in the X-Y plane.

QUADRATIC

23. The user may need a curved line segment which is not circular or elliptical. The quadratic line segment is provided for this purpose. The command format is

"Quadratic" N1, N2, XQQ, YQQ, ZQQ

N1 and N2 are the point labels of the beginning and end of the quadratic line segment and (XQQ, YQQ, ZQQ) is an interpolation point (Figure 5) that the

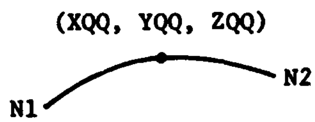

Figure 5. Quadratic plotting

curve must pass through. The following data file results in the base shown in Figure 6:

```
10 POINTS 4
20 1 0 -5
30 2 5 0
40 3 0 5
50 4 -5 0
60 QUAD 1 2 4 -3
70 GUAD 2 3 3 4
80 QUAD 3 4 -4 3
90 QUAD 4 1 -3 -4
```

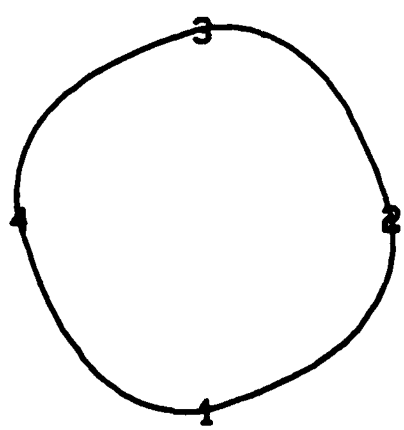

Figure 6. QUADRATIC command

BASE

24. The user next describes the order in which the points and curved line segments are connected by giving the BASE command. The format for this command is

"Base" NHOLE

where NHOLE is the number of holes in the base. After the BASE command is given in the interactive mode, the connectivity data are requested for the outer boundary and each hole:

CONNECTIVITY DATA?

The connectivity data (see Figure 7) are described by first giving the number

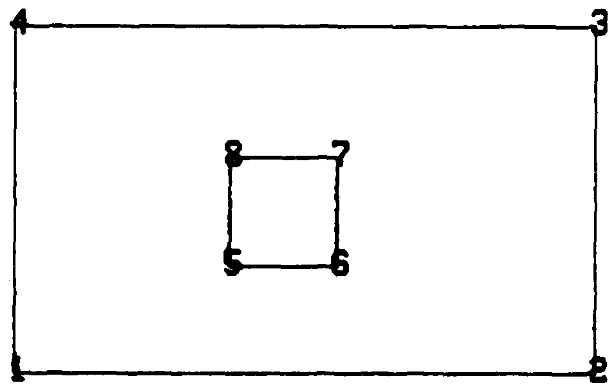

Figure 7. Sample base

of points forming the outer boundary followed by the point labels in counterclockwise order for the outer boundary and then the number of points forming the hole followed by the point labels in clockwise order. The interactive question and answer sequence used to generate the base in Figure 7 is

```
 COMMAND ?
I>POINTS 8
 LABEL X, Y, Z
I>1 0 0 268
I>2 54 0 268
I>3 54 32 268
I>4 0 32 268
I?5 20 10 268
I>6 30 10 268
I>7 30 20 268
I>8 20 20 268
 COMMAND ?
I>BASE 1
 OUTER BOUNDARY DATA
 CONNECTIVITY DATA ?
I>4 1 2 3 4
 DATA FOR HOLE                  1
 CONNECTIVITY DATA ?
I>4 8 7 6 5
```

If these data were placed into a data file, the file would appear as:

```
10 POINTS 8
20 1 0 0 268
30 2 54 0 268
40 3 54 32 268
50 4 0 32 268
60 5 20 10 268
70 6 30 10 268
80 7 30 20 268
90 8 20 20 268
100 BASE 1
110 4 1 2 3 4
120 4 8 7 6 5
```

UPLIFT

25. When one or more of the base pressures are negative on the first iteration, a new effective base and, possibly, a new value for uplift (see Part III) must be computed. Thus, the uplift data must be specified separately from the other forces and moments of the load case. These data are provided by giving the uplift pressure at each of the defined points on the base. The format for the UPLIFT command is

"Uplift" NPT

where NPT is the number of points for which uplift is now to be specified. After this line, the identification label and corresponding value of uplift pressure are given for each point. Below is an example of the UPLIFT command:

```
10 POINTS 4
20 1 0 0 268
30 2 54 0 268
40 3 54 32 268
50 4 0 32 268
60 UPLIFT 4
70 1 2.000
80 2 0.125
90 3 0.125
100 4 2.000
```

Zero is assumed for uplift for all points not specified.

PHI

26. The resistance to sliding is computed from the formula

$$R = N \tan\phi + sA \tag{1}$$

where R is the resistance, N is the normal component of the force applied to the base, ϕ (phi) is the angle of internal friction of the foundation material in degrees, s is the shear strength or cohesion of the foundation material, and A is the effective area. The PHI command is used to specify the ϕ angle. Its format is

"PHI" ANGLE

where ANGLE is an angle specified in degrees.

SHRSTR

27. THE SHRSTR command is used to specify the shear strength in consistent units. Its format is

"SHrstr" S

where S is the shear strength.

SANGLE

28. The SANGLE command allows the user to specify in what direction the shear friction factor of safety, as given in Engineer Technical Letter (ETL) 1110-2-184,* is to be computed. Its format is:

"SAngle" "Default"

"SAngle" SANG

SANG is the angle in the horizontal plane measured from the global X axis for which sliding stability is to be evaluated. The default angle is the angle formed by the horizontal component of the resultant load and the global X axis. Note, however, that sliding is always computed tangent to the plane of analysis.

DENSITY

29. The default value for the density of water is assumed to be 0.0625 kips/ft^3 (0.001 kg/m^3). The user can change this value to his set of consistent units by using the DENSITY command. Its format is

"Density" DENS

where DENS is the specified density of water. Note that this command would be used if, for instance, a metric system of units were being used.

CASE

30. After the user has specified points and any curves, defined the connectivity for the base, specified any uplift values, and defined PHI, SHRSTR, and DENSITY when necessary, he must give the CASE command to define

---

* This and other engineer standards used in development of the General Analysis Module are listed in the Bibliography.

the other applied forces and moments. Its format is

"Case" CNAME, LDTYPE

where CNAME is a one- to four-character identifier and LDTYPE is the load type. LDTYPE may have three values:

a. 1 - long term.

b. 2 - short term.

c. 3 - instantaneous.

Specifying an instantaneous load type (LDTYPE=3) prevents the uplift from being modified when the effective base is modified. After the CASE command is given, the next data required (either interactively or from a data file) are the three force components (F_x, F_y, F_z) and moments (M_x, M_y, M_z) about the global coordinate system excluding the contribution from uplift. An example data file is

```
10 POINTS 4
20 1 0 0 268
30 2 54 0 268
40 3 54 32 268
50 4 0 32 268
60 UPLIFT 4
70 1 2.000
80 2 0.125
90 3 0.125
100 4 2.000
110 PHI 19.6
120 SHRSTR .22
130 BASE
140 4 1 2 3 4
150 CASE NORM 1
160 1100 0 -5800 -93000 444000 0
```

After the data for the CASE command are given, the program performs the computations and begins output. A detailed discussion of the output begins in paragraph 36.

INPUT

31. This command allows the user to input or read into memory a permanent data file saved on disc. Its format is

"INPut" FLNM1
"INPut" FLNM1 "P"

where FLNM1 is a 1- to 20-character file description. If the P is also typed, a detailed printout of the input file is printed on the terminal as if it had been done interactively.

END

32. This command is given to terminate running of the program. Its format is

"ENd"

GO

33. This command is used when the program is being used for a specific structure such as a dam or lock. Giving the GO command automatically causes the program to return to do the next load case. The format for this command is

"GO"

RETURN

34. This command is used to return to the question

STRUCTURE TYPE OR GENERAL MODULE?

so that the user can select another module. The format for this command is

"REturn"

CLEAR

35. This command is used to clear all definition of geometry from memory so as to begin a new problem. Its format is

"CLear"

Output

36. Each time a CASE command is given, an analysis is performed and the output immediately follows.

Printout of input

37. The user is first asked:

DO YOU WISH TO SEE A SUMMARY OF THE ANALYSIS INPUT DATA?

If YES is typed, the following table is printed:

```
                    LOAD CASE NORM CATEGORY =     1

                INPUT FORCES AND MOMENTS EXCLUDING UPLIFT

  FX =     1100.000       FY =        0.           FZ =    -5800.000
  MX =    -93000.0        MY =      444000.0       MZ =          0.

                 INPUT COORDINATES AND UPLIFT VALUES

NAME              X               Y              Z              UPLIFT

1                 0.              0.             268.000          2.000
2                54.000           0.             268.000          0.125
3                54.000          32.000          268.000          0.125
4                 0.             32.000          268.000          2.000

 PHI =        19.60   SHRSTR =          0.22   SANGLE =        DEFAULT
                    DENSITY =        0.0625
```

Final kern plot

38. The user in most cases is next asked the question:

DO YOU WISH TO SEE THE FINAL KERN PLOT?

IF YES is given, the following are plotted:

a. Outline of the modified base (original base projected onto the plane of investigation) with solid lines.

b. Kern with dashed lines.

c. Circled + marking the centroid of the base.

d. + marking the position of the load resultant.

e. Values of eccentricity.

f. Distance of load resultant to kern.

Figure 8 shows the final kern plot for the data file given in paragraph 30. When this plot is completed, the bell will ring and the program will pause.

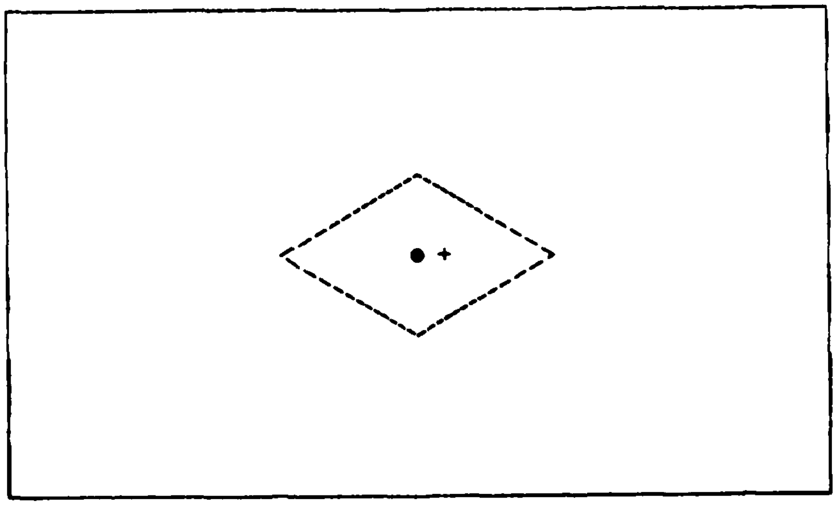

Figure 8. Final kern plot

:s

› continue, the user hits the carriage return. The final results
›llows:

```
        LOAD CASE NORM CATEGORY =     1

          FINAL BASE AREA PROPERTIES

 1728.000        IXP =      147456.0       IYP =      419904.0
   27.000       YBAR =        16.000      ZBAR =       268.000
    0.         ZNANG =         0.        PXANG =         0.

       SUMMARY OF FINAL FORCES AND MOMENTS

                     --INPUT--

1100.000         FY =          0.         FZ =     -5800.000
-93000.0         MY =     444000.0        MZ =            0.

                --COMPUTED UPLIFT--

   0.            FY =          0.         FZ =      1836.000
 29376.0         MY =     -34992.0        MZ =            0.

                     --TOTAL--

1100.000         FY =          0.         FZ =     -3964.000
-63624.0         MY =     409008.0        MZ =            0.

FINAL IN PLANE COORDINATES AND BASE PRESSURES

        X              Y              Z          PRESSURE

        0.             0.          268.000          1.811
      54.000           0.          268.000          2.734
      54.000         32.000        268.000          2.777
        0.           32.000        268.000          1.854

      FINAL SHEAR FRICTION FACTOR OF SAFETY

   19.60   SHRSTR =          0.22   SANGLE =          0.

  FACTOR OF SAFETY =          1.63

             EFFECTIVE BASE = 100.0%
```

ıe output data are described in the following tabulation:

Variable	Description
CATEGORY	1 - long term, 2 - short term, 3 - instantaneous
AREA	Area of the base in the plane of analysis
IXP	X principal moment of area in the local coordinate system
IYP	Y principal moment of area in the local coordinate system
XBAR	X centroid in global coordinates
YBAR	Y centroid in global coordinates
ZBAR	Z centroid in global coordinates
XYANG	Angle in the X-Y plane that the direction of the plane of analysis makes with the global X-axis (see Figure 9). This corresponds to a rotation about the global Z-axis to form the prime set of axes
ZNANG	Angle between the global Z axis and the upward normal to the plane of analysis (see Figure 9). This corresponds to a rotation about the Y'-axis to form the double prime coordinate system
PXANG	Angle between local X axis and the principal X axis in the local coordinate system (see the angle THETA in Figure 15)
FX	Force in the global X direction
FY	Force in the global Y direction
FZ	Force in the global Z direction
MX	Moment about the global X axis
MY	Moment about the global Y axis
MZ	Moment about the global Z axis
NAME	Point label
(X,Y,Z)	In plane coordinates of point
PRESSURE	Computed bearing or base pressure
FACTOR OF SAFETY	Shear friction factor of safety

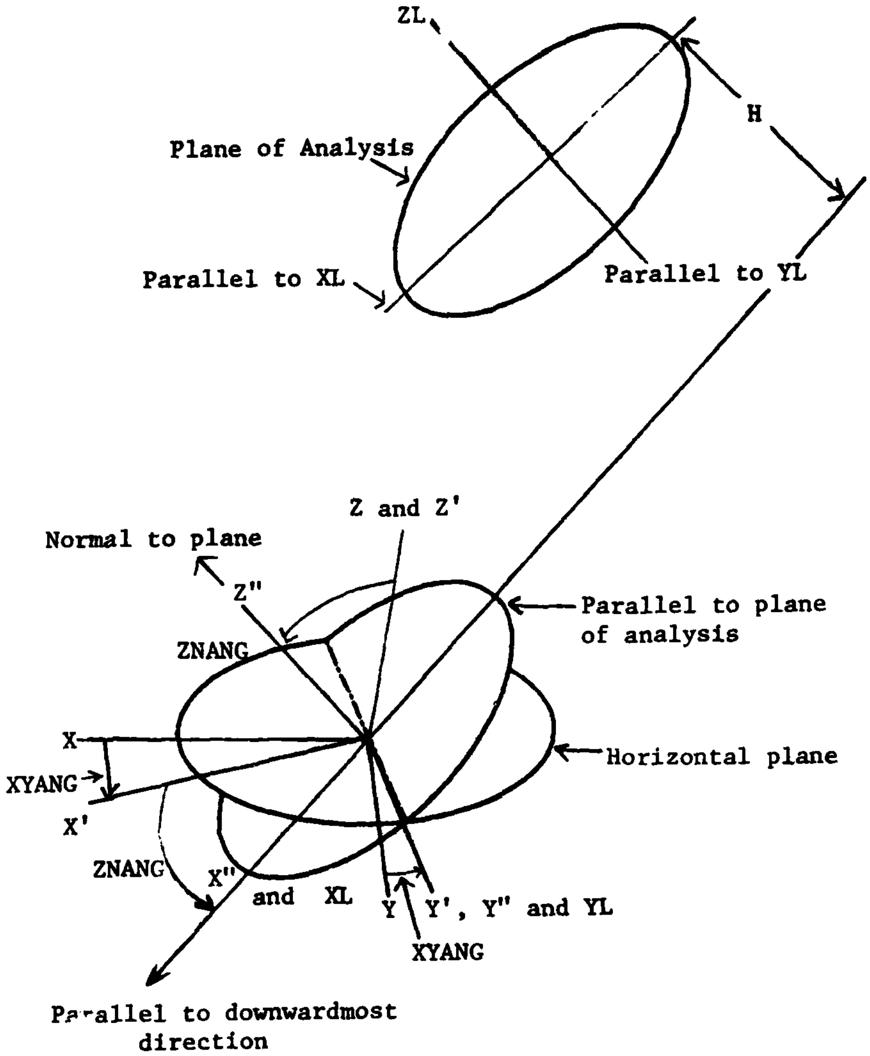

Figure 9. Angles of rotation

Intermediate kern plot

41. If any of the base pressures are negative and the program has to iterate to find a new effective base, the user first has the option of viewing a kern plot before the iteration begins. The question asked is

DO YOU WANT TO SEE THE INTERMEDIATE KERN PLOT?

An example of the intermediate kern plot is given in paragraph 44.

Intermediate results

42. When the intermediate kern plot is complete, the bell will ring and the program will pause. A carriage return will cause the program to continue and print the intermediate results (see the example in paragraph 44). If all the intermediate base pressures are zero or positive, the final results are the same as the intermediate ones and thus are the only ones printed. Note also that the load resultant is inside the kern when the base pressures are all positive.

Additional Sample Problems

43. To help illustrate the features of this module, some additional sample problems will now be presented.

Negative pressures

44. The following data file is a simple example of how the iterative process works when one or more of the initial base pressures are negative:

```
10 POINTS 4
20 1 0 0
30 2 10 0
40 3 10 10
50 4 0 10
60 BASE
70 4 1 2 3 4
80 CASE TEST 1
90 0 0 -1 -7 7 0
```

The intermediate kern plot is shown in Figure 10.

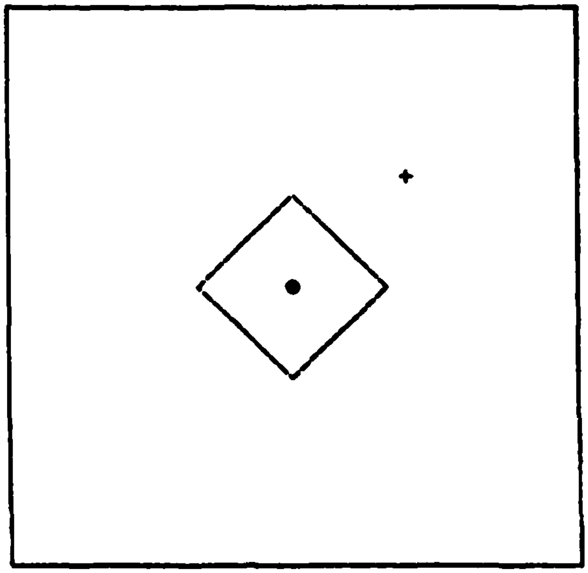

Figure 10. Intermediate kern plot, negative pressures example

The intermediate results are:

LOAD CASE TEST CATEGORY = 1

COMPUTED BASE AREA PROPERTIES

AREA =	100.000	IXP =	833.3	IYP =	833.3
XBAR =	5.000	YBAR =	5.000	ZBAR =	0.
XYANG =	0.	ZNANG =	0.	PXANG =	0.

SUMMARY OF FORCES AND MOMENTS

--INPUT--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-7.0	MY =	7.0	MZ =	0.

--COMPUTED UPLIFT--

FX =	0.	FY =	0.	FZ =	0.
MX =	0.	MY =	0.	MZ =	0.

--TOTAL--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-7.0	MY =	7.0	MZ =	0.

(Continued)

COMPUTED IN PLANE COORDINATES AND BASE PRESSURES

NAME	X	Y	Z	PRESSURE
1	0.	0.	0.	-0.014
2	10.000	0.	0.	0.010
3	10.000	10.000	0.	0.034
4	0.	10.000	0.	0.010

COMPUTED SHEAR FRICTION FACTOR OF SAFETY

PHI = 0. SHRSTR = 0. SANGLE = 0.

FACTOR OF SAFETY = 9999.99

The final kern plot is given in Figure 11.

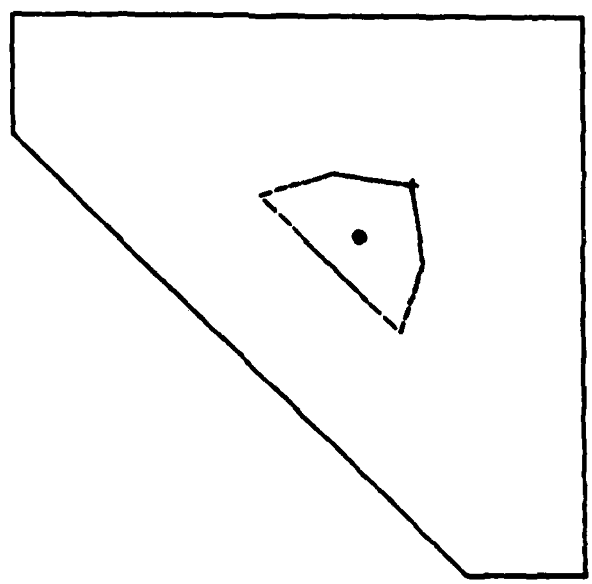

Figure 11. Final kern plot,
negative pressures example

The results after iteration are:

LOAD CASE TEST CATEGORY = 1

FINAL BASE AREA PROPERTIES

AREA =	68.846	IXP =	271.6	IYP =	671.6
XBAR =	6.072	YBAR =	6.072	ZBAR =	0.
XYANG =	0.	ZNANG =	0.	PXANG =	-45.000

SUMMARY OF FINAL FORCES AND MOMENTS

--INPUT--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-7.0	MY =	7.0	MZ =	0.

--COMPUTED UPLIFT--

FX =	0.	FY =	0.	FZ =	0.
MX =	0.	MY =	0.	MZ =	0.

--TOTAL--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-7.0	MY =	7.0	MZ =	0.

FINAL IN PLANE COORDINATES AND BASE PRESSURES

NAME	X	Y	Z	PRESSURE
2-1	7.894	0.	0.	-0.000
2	10.000	0.	0.	0.007
3	10.000	10.000	0.	0.041
4	0.	10.000	0.	0.007
4-1	0.	7.894	0.	0.000

FINAL SHEAR FRICTION FACTOR OF SAFETY

PHI =	0.	SHRSTR =	0.	SANGLE =	0.

FACTOR OF SAFETY = 9999.99

EFFECTIVE BASE = 68.8%

Nonhorizontal nonplanar base

45. The input data are as follows:

```
10 POIN 4
20 1 0 0 -1
30 2 10 0 0
40 3 10 10 2
50 4 0 10 0
60 BASE
70 4 1 2 3 4
80 CASE C1 1
90 0 0 -1 -5.5 5.5 0
```

Figure 12 shows the final kern plot.

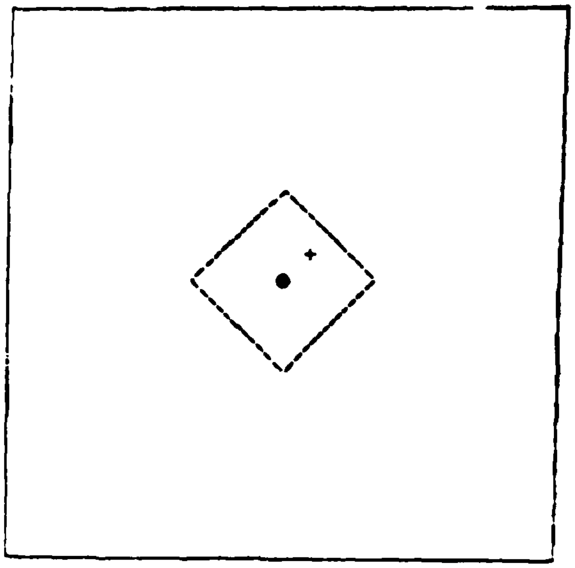

Figure 12. Final kern plot, nonhorizontal nonplanar base example

Final results are:

LOAD CASE C1 CATEGORY = 1

FINAL BASE AREA PROPERTIES

AREA =	102.225	IXP =	890.3	IYP =	851.9
XBAR =	5.012	YBAR =	5.012	ZBAR =	0.254
XYANG =	-135.000	ZNANG =	11.977	PXANG =	-45.000

SUMMARY OF FINAL FORCES AND MOMENTS

--INPUT--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-5.5	MY =	5.5	MZ =	0.

--COMPUTED UPLIFT--

FX =	0.	FY =	0.	FZ =	0.
MX =	0.	MY =	0.	MZ =	0.

--TOTAL--

FX =	0.	FY =	0.	FZ =	-1.000
MX =	-5.5	MY =	5.5	MZ =	0.

FINAL IN PLANE COORDINATES AND BASE PRESSURES

NAME	X	Y	Z	PRESSURE
1	0.036	0.036	-1.239	0.004
2	9.964	-0.036	0.239	0.010
3	10.036	10.036	1.761	0.015
4	-0.036	9.964	0.239	0.010

FINAL SHEAR FRICTION FACTOR OF SAFETY

PHI =	0.	SHRSTR =	0.	SANGLE =	-135.00

FACTOR OF SAFETY = 0.

EFFECTIVE BASE = 100.0%

Powerhouse analysis

46. The following example is an analysis of a powerhouse provided by Mr. Charles W. Kling, Mobile District. The data file for the analysis appears as follows:

```
10 PO 22
20 D 80 113
30 C 0 113
40 B 0 0
50 A 80 0
60 1 72.5 113
70 2 72.5 83.4
80 3 71 73.5
90 4 65.7 63
100 5 59.2 53
110 6 52.6 39.9
120 7 34.2 38
130 8 21.9 53
140 9 13.2 63
150 10 9 73.5
160 11 7.5 83.4
170 12 7.5 113
180 13 36.5 113
190 14 36.5 73.5
200 15 39.1 63
210 16 42.6 63
220 17 43.5 73.5
230 18 43.5 113
240 BASE 1
250 4 A B C D
260 18 1 2 3 4 5 6 7 8 9 10 11 12
270    13 14 15 16 17 18
280 CASE 1ST 2
290 0 0 -35562 -2126942 1473689 0
```

The final kern plot is shown in Figure 13. The output appears as follows:

```
                 LOAD CASE 1ST  CATEGORY =    2

                   FINAL BASE AREA PROPERTIES

 AREA =     5374.850       IXP =     4684320.6      IYP =    3661498.3
 XBAR =       39.934      YBAR =        40.255     ZBAR =           0.
XYANG =           0.     ZNANG =            0.    PXANG =       -0.137
```

(Continued)

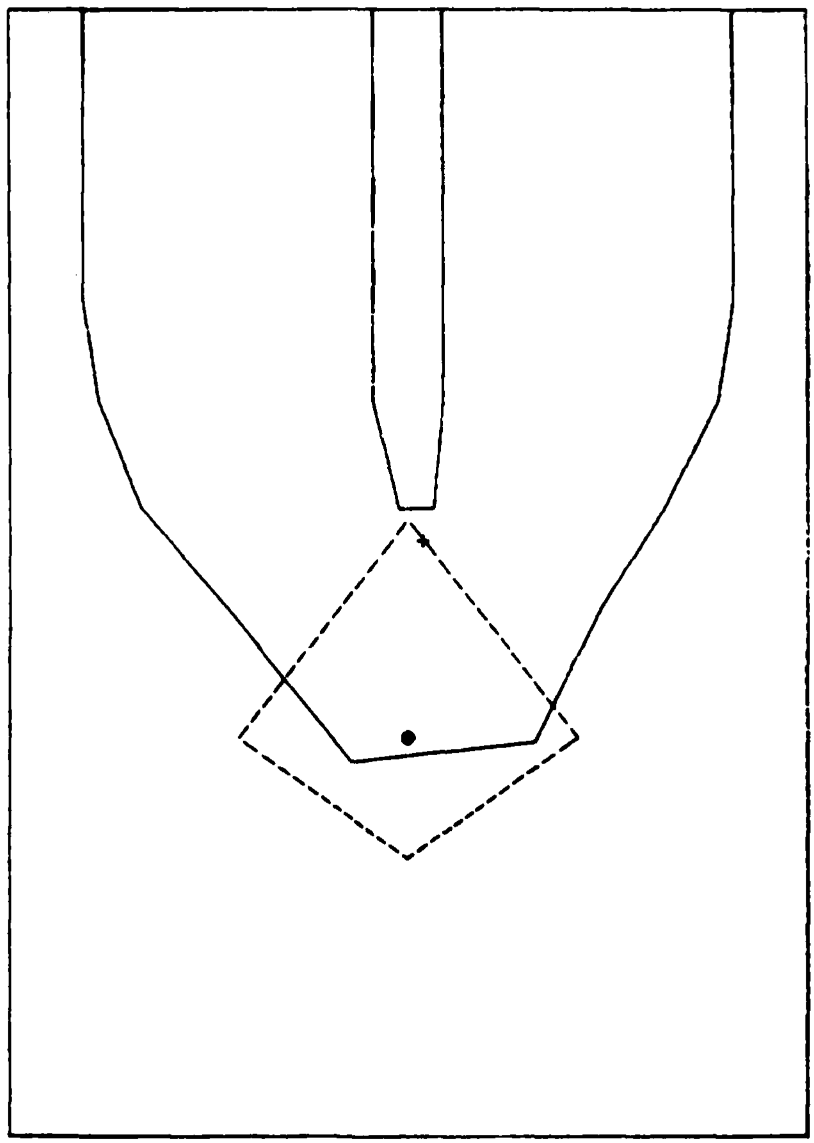

Figure 13. Final kern plot,
powerhouse analysis example

SUMMARY OF FINAL FORCES AND MOMENTS

--INPUT--

FX =	0.	FY =	0.	FZ =	-35562.000
MX =	-2126942.0	MY =	1473689.0	MZ =	0.

--COMPUTED UPLIFT--

FX =	0.	FY =	0.	FZ =	0.
MX =	0.	MY =	0.	MZ =	0.

--TOTAL--

FX =	0.	FY =	0.	FZ =	-35562.000
MX =	-2126942.0	MY =	1473689.0	MZ =	0.

FINAL IN PLANE COORDINATES AND BASE PRESSURES

NAME	X	Y	Z	PRESSURE
A	80.000	0.	0.	1.223
B	0.	0.	0.	0.060
C	0.	113.000	0.	16.835
D	80.000	113.000	0.	17.997
1	72.500	113.000	0.	17.888
2	72.500	83.400	0.	13.494
3	71.000	73.500	0.	12.003
4	65.700	63.000	0.	10.367
5	59.200	53.000	0.	8.788
6	52.600	39.900	0.	6.748
7	34.200	38.000	0.	6.198
8	21.900	53.000	0.	8.246
9	13.200	63.000	0.	9.604
10	9.000	73.500	0.	11.102
11	7.500	83.400	0.	12.550
12	7.500	113.000	0.	16.944
13	36.500	113.000	0.	17.365
14	36.500	73.500	0.	11.502
15	39.100	63.000	0.	9.981
16	42.600	63.000	0.	10.032
17	43.500	73.500	0.	11.603
18	43.500	113.000	0.	17.467

FINAL SHEAR FRICTION FACTOR OF SAFETY

PHI =	0.	SHRSTR =	0.	SANGLE =	0.

FACTOR OF SAFETY = 9999.99

EFFECTIVE BASE = 100.0%

PART III: THEORY AND PROCEDURE

Introduction

47. This part describes how some of the more significant output data are computed. The description will involve a theoretical discussion in some cases, such as that of base pressure computation. Other times, such as for the description on how uplift is computed, the discussion will take the form of a description of procedure.

Assumptions

48. The following assumptions are made in this analysis:

- a. The effects due to the elastic properties of both the structure and foundation have been ignored; rigid body motion assumed; and limit equilibrium methods utilized.
- b. The soil and water loads are computed separately from that of the structure. Thus, no soil-structure interaction is considered.
- c. The analysis is performed on a planar approximation of the base.
- d. The analysis is thus performed using only the force components (F_x, F_y, F_z) and moment components (M_x, M_y, M_z) and the planar approximation of the base.
- e. The bearing or base pressures thus vary linearly over the base (general flexure formula for biaxial bending).
- f. The shear friction formula is used for computing the factor of safety against sliding.

Sign Convention

49. A strictly right-handed coordinate system for coordinates, forces, and moments is used. The weight of the structure, therefore, is considered a negative number. Compressive stresses or pressures are considered positive, while tensile stresses are negative.

Base Pressures

Formula

50. Consider the planar horizontal base with the origin at the centroid as shown in Figure 14. The base pressures are computed from the general

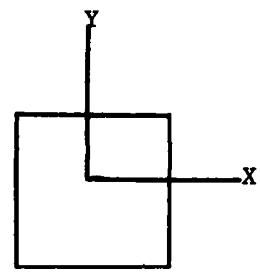

Figure 14. Horizontal base

flexure equation

$$p = -\frac{F_z}{A} + \left(\frac{M_y}{I_y}\right) X - \left(\frac{M_x}{I_x}\right) Y \tag{2}$$

if the principal axes of the base are also the X and Y axes. Here, A is the area of the base, I_x is the X moment of area, and I_y is the Y moment of area.

et us start with the assumption that pressure varies linearly over

Thus,

$$p = a + bX + cY \tag{3}$$

, and c are constants to be evaluated.

First, integrate both sides of Equation 3 over the area of the base.

$$\int_A p\,da = a\int_A da + b\int_A X\,da + c\int_A Y\,da$$

ing Z forces,

$$\int_A p\,da + F_z = 0$$

$$\int_A X\,da = 0$$

$$\int_A Y\,da = 0$$

X and Y centroid are both zero. Therefore,

$$-F_z = aA + b(0) + c(0)$$

$$a = -\frac{F_z}{A} \tag{4}$$

Second, multiply both sides of Equation 3 by X and integrate over

$$\int_A Xp\,da = a\int_A X\,da + b\int_A X^2\,da + c\int_A XY\,da$$

ming Y moments,

$$-\int_A Xp\,da + M_y = 0$$

By definition,

$$I_y = \int_A X^2 da$$

and since the principal axes coincide with the coordinate axes,

$$\int_A XYda = 0$$

Thus,

$$M_y = a(0) + bI_y + c(0)$$

$$b = \frac{M_y}{I_y}$$

54. Last, multiply both sides of Equation 3 by Y and integrate over the area:

$$\int_A Ypda = a \int_A Yda + b \int_A XYda + c \int_A Y^2 da$$

Summing X moments,

$$\int_A Ypda + M_x = 0$$

By definition,

$$I_x = \int_A Y^2 da$$

Collecting terms,

$$-M_x = a(0) + b(0) + c\ I_x$$

$$c = -\frac{M_x}{I_x}$$

Combining Equations 3, 4, 5, and 6 gives the desired result:

$$p = -\frac{F_z}{A} + \left(\frac{M_y}{I_y}\right) X - \left(\frac{M_x}{I_x}\right) Y$$

General formulation

55. In general, however, the coordinate system will neither have its origin at the centroid of the base nor align with its principal axes (see Figure 15). The X'-Y' coordinate system has its origin at the centroid of the base and aligns with the X-Y coordinate system. The X"-Y" coordinate system

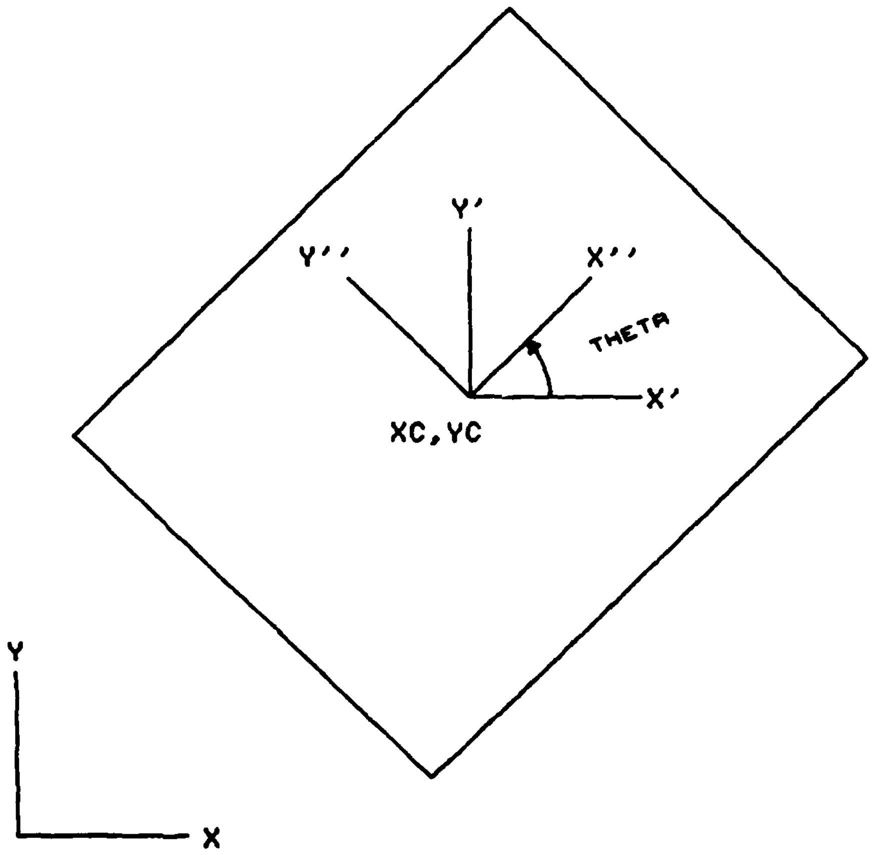

Figure 15. General base

is aligned with the principal axes of the plane and is achieved by rotating the X'-Y' axes an angle θ. Thus, from Equation 2,

$$p = -\frac{F_z}{A} + \left(\frac{M''_y}{I''_y}\right) X'' - \left(\frac{M''_x}{I''_x}\right) Y'' \tag{7}$$

To put this equation in terms of the X-Y system, both a translation and a rotation are required. First,

$$X' = X - X_c$$
$$Y' = Y - Y_c$$

Next,

$$[X''\ Y''] = [X'\ Y'] \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

Applying this translation and rotation to the moment gives

$$M'_x = M_x - F_z Y_c$$

$$M'_y = M_y + F_z X_c$$

$$\begin{bmatrix} M''_x & M''_y \end{bmatrix} = \begin{bmatrix} M'_x & M'_y \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

Applying this translation and rotation to the moment of areas gives

$$\begin{aligned} I_x' &= \int_A Y'^2 da \\ &= \int_A (Y - Yc)^2 da \\ &= I_x - 2Y_c(Y_c A) + Y_c^2(A) \\ &= I_x - Y_c^2 A \\ I'_{xy} &= \int_A X'Y' da \\ &= \int_A (X - X_c)(Y - Y_c) da \\ &= I_{xy} - X_c(Y_c A) - Y_c(X_c A) + X_c Y_c A \\ &= I_{xy} - X_c Y_c A \end{aligned}$$

$$I'_y = \int_A X'^2 da$$
$$= \int_A (X - X_c)^2 da$$
$$= I_y - 2X_c(X_c A) + X_c^2 A$$
$$= I_y - X_c^2 A$$

$$\begin{bmatrix} I''_x & 0 \\ 0 & I''_y \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I_x & -I_{xy} \\ -I_{xy} & I_y \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

Equation 7 can now be written

$$p = -\frac{F_z}{A} + [X-X_c \quad Y-Y_c] \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \dfrac{M''_y}{I''_y} \\ -\dfrac{M''_x}{I''_x} \end{bmatrix}$$

To get the form

$$p = a + bX + cY \qquad \text{(2bis)}$$

$$a = -\frac{F_z}{A} + [X_c \; Y_c] \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} -\dfrac{M''_y}{I''_y} \\ \dfrac{M''_x}{I''_x} \end{bmatrix}$$

$$b = \frac{M''_y}{I''_y} \cos\theta + \frac{M''_x}{I''_x} \sin\theta \qquad (8)$$

$$c = \frac{M''_y}{I''_y} \sin\theta - \frac{M''_x}{I''_x} \cos\theta$$

Kern Computation

Definition

56. Given the base in Figure 16, let P be the point at which the normal

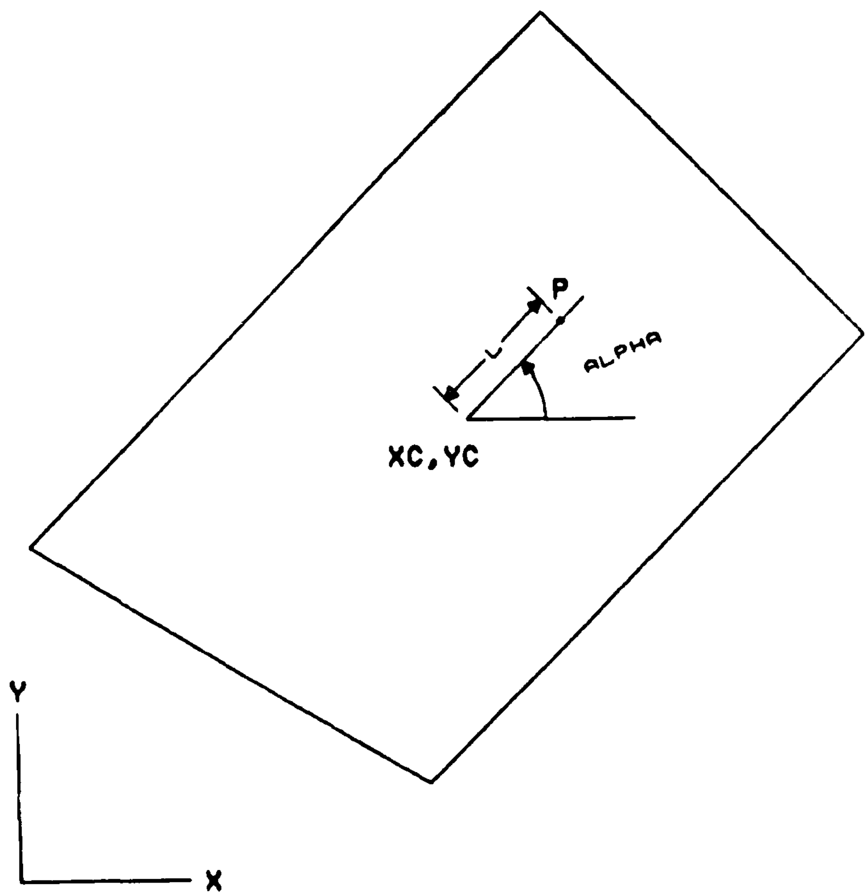

Figure 16. Sample base

force F_z is applied to the base to produce the moments M_x and M_y. Thus,

$$M_x = F_z (Y_c + L \sin \alpha) \tag{9}$$
$$M_y = -F_z (X_c + L \cos \alpha)$$

The kern is defined as that area where, if the point P falls inside it, all of the computed base pressures are positive. This means that if P falls outside the kern, some points on the base will have a negative value.

Derivation

57. Rather than start with Equation 8, let us derive a new set of a, b, and c for

$$p = a + b(X - X_c) + c(Y - Y_c) \qquad (10)$$

First, define the constants

$$\begin{aligned} A_x &= \int_A X da \\ A_y &= \int_A Y da \\ A_{xx} &= \int_A X^2 da \\ A_{xy} &= \int_A XY da \\ A_{yy} &= \int_A Y^2 da \end{aligned} \qquad (11)$$

Integrating both sides of Equation 10 as before gives

$$\begin{aligned} \int_A p da &= a \int_A da + b \int_A (X - X_c) da + c \int_A (Y - Y_c) da \\ -F_z &= aA + b(A_x - X_c A) + c(A_y - Y_c A) \\ &= aA \end{aligned}$$

$$a = -\frac{F_z}{A}$$

$$\int_A X p da = -\frac{F_z}{A} \int_A X da + b \int_A (X - X_c) X da + \int_A (Y - Y_c) X da$$

$$M_y = -F_z \frac{A_x}{A} + b(A_{xx} - X_c A_x) + c(A_{xy} - Y_c A_x)$$

$$M_y = -F_z \frac{A_x}{A} + b\left(A_{xx} - \frac{A_x^2}{A}\right) + c(A_{xy} - A_x A_y) \qquad (12)$$

$$\int_A pY da = -\frac{F_z}{A}\int_A Y da + b\int_A (X - X_c) Y da + c\int_A (Y - Y_c) Y da$$

$$-M_x = -F_z\frac{A_y}{A} + b(A_{xy} - X_c A_y) + c(A_{yy} - Y_c A_y)$$

$$-M_x = -F_z\frac{A_y}{A} + b\left(A_{xy} - \frac{A_x A_y}{A}\right) + c\left(A_{yy} - \frac{A_y^2}{A}\right) \tag{13}$$

Combining Equations 9-13 gives

$$-F_z\begin{bmatrix} X_c \\ Y_c \end{bmatrix} - F_z L\begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix} = -\frac{F_z}{A}\begin{bmatrix} A_x \\ A_y \end{bmatrix} + \begin{bmatrix} A_{xx} - \frac{A_x^2}{A} & A_{xy} - \frac{A_x A_y}{A} \\ A_{xy} - \frac{A_x A_y}{A} & A_{yy} - \frac{A_y^2}{A} \end{bmatrix}\begin{bmatrix} b \\ c \end{bmatrix}$$

Collecting terms,

$$\begin{bmatrix} A_{xx} - \frac{A_x^2}{A} & A_{xy} - \frac{A_x A_y}{A} \\ A_{xy} - \frac{A_x A_y}{A} & A_{yy} - \frac{A_y^2}{A} \end{bmatrix}\begin{bmatrix} b \\ c \end{bmatrix} = -F_z L\begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix}$$

or

$$\underline{\underline{T}}\begin{bmatrix} b \\ c \end{bmatrix} = -F_z L\begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix}$$

$$\begin{bmatrix} b \\ c \end{bmatrix} = -\underline{\underline{T}}^{-1}\begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix} F_z L$$

Putting these results into Equation 10 gives

$$p = -\frac{F_z}{A}\left(1 + [X-X_c \quad Y-Y_c]\,\underline{\underline{T}}^{-1}\begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix} AL\right)$$

58. The kern is computed using the following two assumptions:

a. The force F_z applied at any point on the kern will cause the pressures to be zero at some point on the base.

b. Assuming the base is approximated by a series of straight lines, the point where pressure first becomes zero will always be a vertex of the polygon forming the base.

Thus, along any ray forming an angle α with the horizontal, find the length L such that all pressures at the vertices of the base are zero or positive. The value of L making the pressure zero at the "ith" vertex from Equation 14 is

$$L_i = -\frac{1}{A[X_i - X_c \quad Y_i - Y_c] \; \underline{\underline{T}}^{-1} \begin{bmatrix} \sin\alpha \\ \cos\alpha \end{bmatrix}} \tag{15}$$

Check all vertices and choose the smallest positive L_i.

$$L_{kern} = \Sigma_i \min \text{ (positive } L_i)$$

This process is repeated until the kern is clearly defined.

Base of Analysis

59. All of the above derivations start with the assumption of a horizontal base. Actually, the user specifies an area or surface of investigation which may be neither horizontal nor planar. What the program does, therefore, is to compute a planar base of analysis from the base input by the user.

Plane of analysis

60. The plane of analysis is computed by doing a least squares fit on the N data points describing the base. The criterion used is to minimize the sum of the vertical distance squared from the N points to the plane of

analysis to be determined. The equation of the plane is

$$Z = a + bX + cY \tag{16}$$

where a, b, and c are constants to be computed. The least squares expression is

$$\sum_{i=1}^{N} (a + bX_i + cY_i - Z_i)^2 = \min$$

This gives the following system of simultaneous linear equations to solve for a, b, and c:

$$\begin{aligned} a \sum_{i=1}^{N} X_i + b \sum_{i=1}^{N} X_i + c \sum_{i=1}^{N} X_iY_i &= \sum_{i=1}^{N} X_iZ_i \\ a \sum_{i=1}^{N} Y_i + b \sum_{i=1}^{N} X_iY_i + c \sum_{i=1}^{N} Y_i^2 &= \sum_{i=1}^{N} Y_iZ_i \\ aN + b \sum_{i=1}^{N} X_i + c \sum_{i=1}^{N} Y_i &= \sum_{i=1}^{N} Z_i \end{aligned} \tag{17}$$

Local coordinate system

61. Now that a, b, and c are known, the new set of points for the modified base (plane of analysis) is computed from Equation 16. It should be noted that, if the original points lie in a plane, the new points will be the same as the old ones. Next, the global coordinates, forces, and moments are transformed to a local coordinate system where X_L and Y_L lie in the plane of analysis and Z_L is normal to the plane of analysis. This transformation is made by two rotations and a translation. First, as shown in Figures 9 and 17, a rotation is done about the Z axis so that the new X' axis is parallel to the downwardmost direction of the modified base.

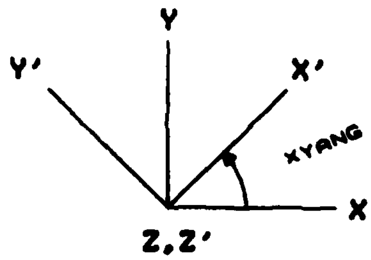

Figure 17. Z axis rotation

Mathematically,

$$[X' \; Y' \; Z'] = [X \; Y \; Z] \begin{bmatrix} \cos\theta_{xy} & -\sin\theta_{xy} & 0 \\ \sin\theta_{xy} & \cos\theta_{xy} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{18}$$

Next, as shown in Figures 9 and 18, a Y' axis rotation is done, as follows:

$$[X'' \; Y'' \; Z''] = [X' \; Y' \; Z'] \begin{bmatrix} \cos\theta_{zn} & 0 & \sin\theta_{zn} \\ 0 & 1 & 0 \\ -\sin\theta_{zn} & 0 & \cos\theta_{zn} \end{bmatrix}$$

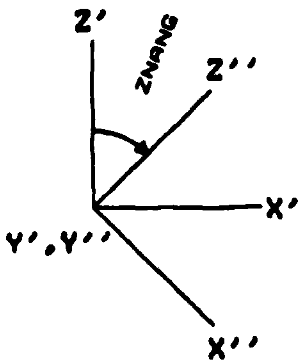

Figure 18. Y' axis rotation

Last, as shown in Figures 9 and 19, a translation to have the plane of

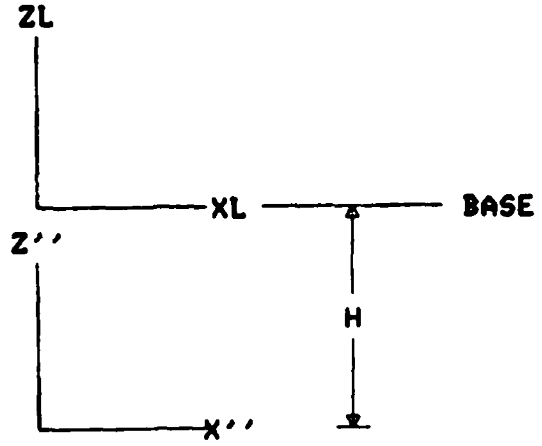

Figure 19. Base in local system

analysis lie in the X_L-Y_L plane is done:

$$X_L = X''$$

$$Y_L = Y''$$

$$Z_L = Z'' - H$$

Forces and moments are transformed exactly as coordinates, except that

$$\begin{aligned} F_{z_L} &= F''_z \\ M_{x_L} &= M''_x + HF''_y \\ M_{y_L} &= M''_y - HF''_x \\ M_{z_L} &= M''_z \end{aligned} \qquad (20)$$

Uplift

62. Uplift pressures can be specified at the points defining the base of investigation. When the original points are replaced by a different set of points that lie in the plane of analysis, the uplift values must also be modified. The equation used is

$$U_{new} = U_{old} + \gamma_w (Z_{old} - Z_{new}) \tag{21}$$

where γ_w is the density of water.

63. Next, the contribution of uplift to the other forces and moments must be computed. In addition to the uplift pressures being specified at certain points on the boundary, some assumptions must be made as to what values the uplift has at other points on the base.

64. First, uplift is assumed to vary linearly along the line segments between the specified points. Next, the base is rotated (for computation purposes only) so that the line segment with the maximum gradient

$$i = \frac{U_1 - U_2}{L}$$

is parallel to the local X axis. Here, U_1 and U_2 are the uplift values specified at the two ends of a line segment, and L is the length of the line segment. Next, as shown in Figure 20, the base is divided into horizontal strips. Note that a horizontal line is always created from a vertex and sometimes midway between vertices. Note also that vertical lines are drawn when the midlines are needed to further subdivide the base. Uplift pressures are assumed to vary linearly along these horizontal lines.

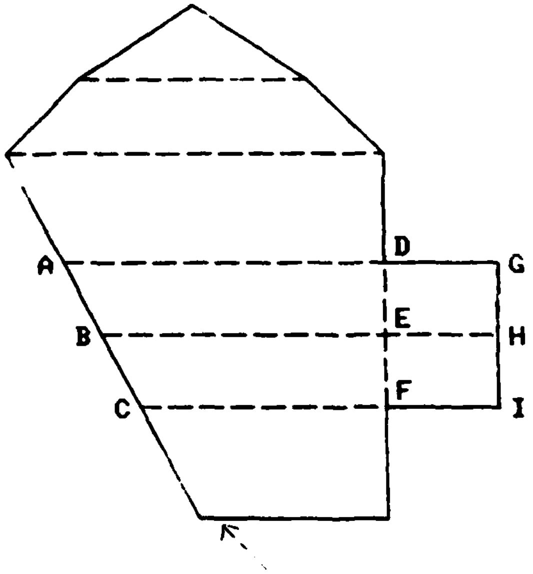

Figure 20. General base

Combining that assumption with the linear variation along the boundary assumption allows all the uplift values to be computed at the vertices of each of the constructed triangles or quadrilaterals. For instance, U_B is computed from U_A and U_C, and U_H is computed from U_G and U_I. Then, U_E can be computed from U_B and U_H.

compute the uplift for any point inside a triangular element, a
:ion is assumed. That is,

$$U = a + bX_L + cY_L$$

and c are constants that can be evaluated from the corner values.
r the quadrilateral element, the isoparametric variation is

$$U = \frac{1}{4}(1 - S)(1 - T)U_1 + \frac{1}{4}(1 + S)(1 - T)U_2$$

$$+ \frac{1}{4}(1 + S)(1 + T)U_3 + \frac{1}{4}(1 - S)(1 + T)U_4$$

, U_3, and U_4 are the corner values, and S and T are parameters
:tween -1 and 1. For the case of a rectangular base where $U_1 = U_4$
, the above equation reduces to:

$$U = \frac{1}{2}(1 - S)U_1 + \frac{1}{2}(1 + S)U_2$$

$$= \frac{1}{2}(U_1 + U_2) + \frac{U_2 - U_1}{2} S$$

mple linear interpolation.

inally, to compute the contribution of uplift to the forces and
is merely necessary to integrate over each of the individual
Since uplift acts normal to the base, only a Z component of forces
he local coordinate system. Thus,

$$F_u = \int_A U da \tag{22}$$

ent contributions are

$$M_{xu} = \int_A Y_L U da$$

$$M_{yu} = -\int_A X_L U da \tag{23}$$

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APPENDIX A: BUILDING AND MODIFYING DATA FILES

1. This appendix contains some general instructions on how to build and modify data files.

WES and Macon Computer Systems

2. To build a new data file, the user first types

NEW

He then types the file with line numbers until finished. The * will appear after each line is typed. Next, once the file is completed,

SAVE NAME

is typed, where NAME is a file description. If a line is wrong, the user simply retypes it. Then, he types

RESAVE NAME

after making all corrections.

3. Input data files for this program are read with a free-field format. Thus, data are separated by either blanks or commas, and floating-point data that are whole numbers do not need a trailing decimal point. The following is a sample data file building sequence in the style of the U. S. Army Engineer Waterways Experiment Station (WES) and the Office of Personnel Management, Macon, Ga. (Macon), computer systems:

```
NEW
*10 1 10. 0.
*20 2 10. 10.
*30 3 0. 10.
*40 0. 0.
*SAVE DAM1
DATA SAVED-DAM1
*5 POINTS 4
*RESA DAM1
DATA SAVED-DAM1
*LIST

5 POINTS 4
10 1 10. 0.
20 2 10. 10.
30 3 0. 10.
40 0. 0.
```

Control Data Corporation (CDC) Computer System

4. To build a new data file, the user first types

NEW,NAME

where NAME is a one- to seven-character name starting with a letter. Then, he types the file with line numbers until finished. The C> prompt will not reappear after the first line is typed. The user next types

SAVE,NAME

upon completion. If a line is wrong, he simply retypes it. Finally, he types

REPLACE,NAME

after making all corrections.

5. Input data files for this program are read with a free-field format. Thus, data are separated by either blanks or commas, and floating-point data that are whole numbers do not need a trailing decimal point. A CDC computer system sample data file building sequence appears as follows:

```
C>NEW,LOCK1
C>10 POINTS 4
20 1 0 0
30 2 100.5 0
40 3 100.5 20
50
SAVE,LOCK1
C>LIST
10 POINTS 4
20 1 0 0
30 2 100.5 0
40 3 100.5 20
C>50 4 0 20
REPLACE,LOCK1
C>LIST
10 POINTS 4
20 1 0 0
30 2 100.5 0
40 3 100.5 20
50 4 0 20
C>
```

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Tracy, Fred T.
A three-dimensional stability analysis/design program (3DSAD) : Report 3 : General Analysis Module (CGAM) / by Fred T. Tracy (Automatic Data Processing Center, U.S. Army Engineer Waterways Experiment Station) and Charles W. Kling (U.S. Army Engineer District, Mobile). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1982.
51, 3 P. : ill. ; 27 cm. -- (Instruction report ; K-80-4, Report 3)
Cover title.
"June 1982."
"A report under the Computer-Aided Structural Engineering (CASE) Project."
"Prepared for Office, Chief of Engineers, U.S. Army."
Bibliography: p. 51.

1. Computer programs. 2. Stability. 3. Structural stability. 4. 3DSAD (Computer program). I. Kling, Charles W. II. United States. Army. Corps of Engineers. Office of the Chief of Engineers. III. U.S. Army

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TA7.W34i no.K-80-4 Report 3

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	Title	Date
Technical Report K-78-1	List of Computer Programs for Computer-Aided Structural Engineering	Feb 1978
Instruction Report O-79-2	User's Guide: Computer Program with Interactive Graphics for Analysis of Plane Frame Structures (CFRAME)	Mar 1979
Technical Report K-80-1	Survey of Bridge-Oriented Design Software	Jan 1980
Technical Report K-80-2	Evaluation of Computer Programs for the Design/Analysis of Highway and Railway Bridges	Jan 1980
Instruction Report K-80-1	User's Guide: Computer Program for Design/Review of Curvilinear Conduits/Culverts (CURCON)	Feb 1980
Instruction Report K-80-3	A Three-Dimensional Finite Element Data Edit Program	Mar 1980
Instruction Report K-80-4	A Three-Dimensional Stability Analysis/Design Program (3DSAD)	
	Report 1: General Geometry Module	Jun 1980
	Report 3: General Analysis Module (CGAM)	Jun 1982
Instruction Report K-80-6	Basic User's Guide: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Instruction Report K-80-7	User's Reference Manual: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Dec 1980
Technical Report K-80-4	Documentation of Finite Element Analyses	
	Report 1: Longview Outlet Works Conduit	Dec 1980
	Report 2: Anchored Wall Monolith, Bay Springs Lock	Dec 1980
Technical Report K-80-5	Basic Pile Group Behavior	Dec 1980
Instruction Report K-81-2	User's Guide: Computer Program for Design and Analysis of Sheet Pile Walls by Classical Methods(CSHTWAL)	
	Report 1: Computational Processes	Feb 1981
	Report 2: Interactive Graphics Options	Mar 1981
Instruction Report K-81-3	Validation Report: Computer Program for Design and Analysis of Inverted-T Retaining Walls and Floodwalls (TWDA)	Feb 1981
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Technical Report K-81-2	Theoretical Basis for CTABS80: A Computer Program for Three-Dimensional Analysis of Building Systems	Sep 1981
Instruction Report K-82-6	User's Guide: Computer Program for Analysis of Beam-Column Structures with Nonlinear Supports (CBEAMC)	Jun 1982

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